Jet Propulsion Laboratory
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Systems Engineering for ASPIRE: A Low-Cost, High Risk Parachute Test Project

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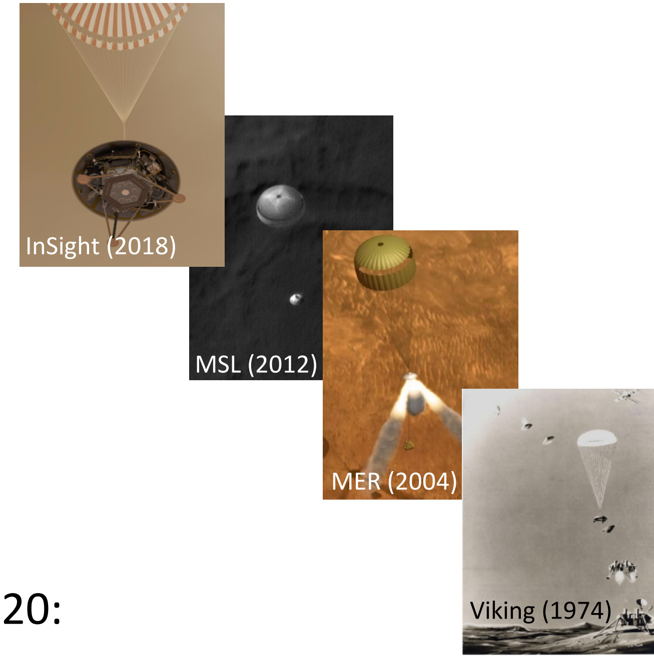
ASPIRE

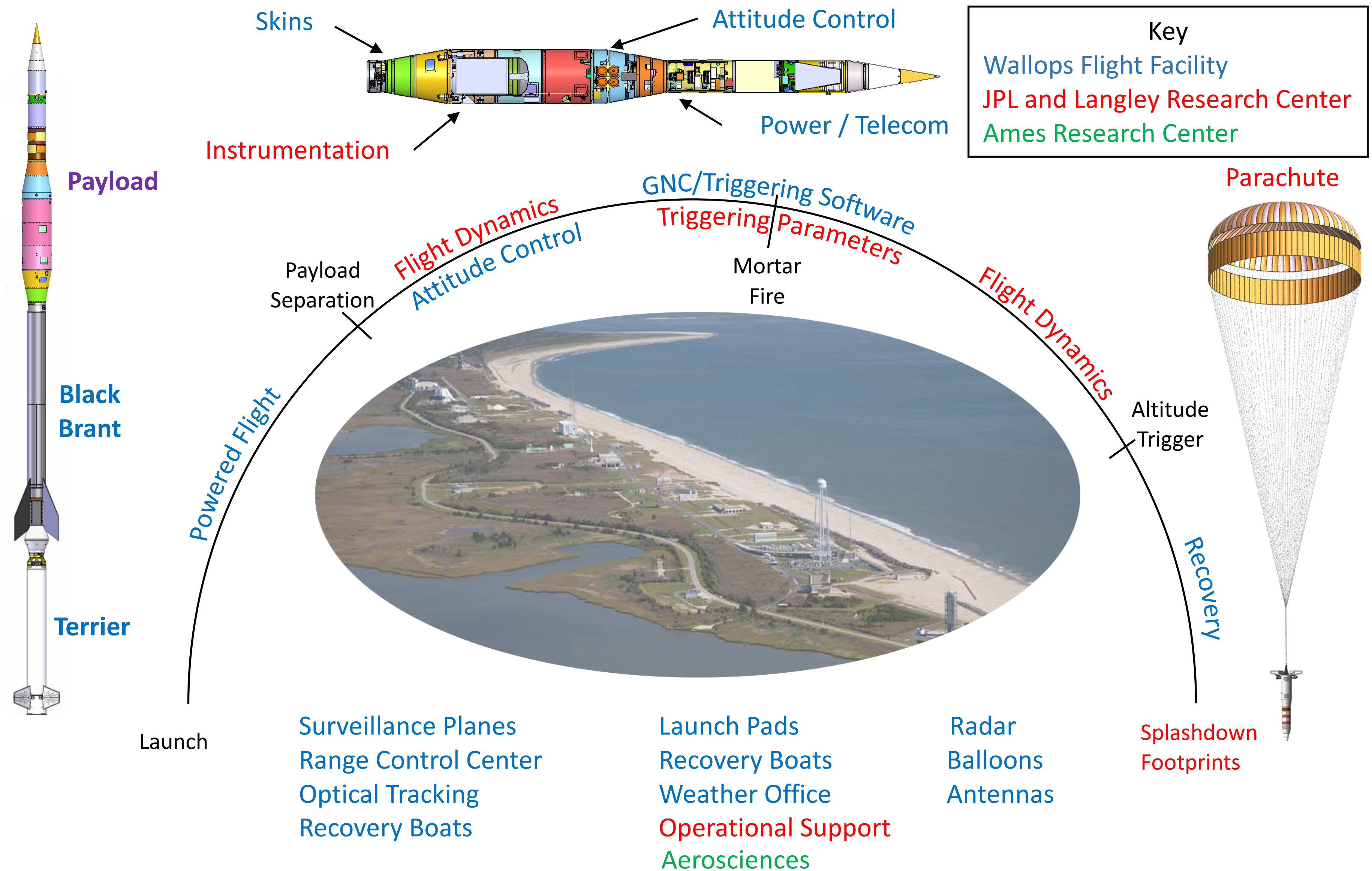
ASPIRE Project Overview

ASPIRE

- Disk-Gap-Band (DGB) parachute: developed in the 60s & 70s for Viking & successfully used in 8 Mars landings.
- **A**dvanced **S**upersonic **P**arachute **I**nflation **R**esearch **E**xperiments Project Objectives:
  - Develop testing capability for supersonic parachutes at Mars-relevant conditions.
  - Deliver 21.5m parachutes to low-density, supersonic conditions on a sounding rocket test platform
  - Acquire data sufficient to characterize flight environment, loads, and performance
- 3 flights focused on testing candidate designs for Mars2020:
  - Built-to-print Mars Science Laboratory (MSL) DGB
  - Strengthened version of MSL DGB with stronger broadcloth
- Architecture developed using a Black Brant IX NASA Sounding Rocket, and heritage sounding rocket program hardware



Architecture, Interfaces, and Responsibilities



A Unique Position

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ASPIRE Architecture and Project Characteristics

- Most missions fall into Class A-D from NASA NPR 8705.4
  - ASPIRE is Type III
- Mission duration of only minutes
- Heavy use of existing hardware and sounding rocket processes
- Comprised of multiple flights
- High allowable risk
  - Per flight allowable success rate 85%
  - Failure of a single flight does not constitute project failure
- Core team about two dozen engineers total
- Only a few months between flights
- Order of magnitude lower cost than typical space missions

However…

Results important to Mars 2020

- Major flagship planetary mission benefits directly from ASPIRE data
- Specific requirements for relevant inflation environment and parachute design
- Time pressure to complete in time to be relevant for 2020 decision making

…and…

Complex System

- Comprised of flight system, mission system, launch vehicle system, and ground system
- Manufacturing, integration, independent analysis and test occur across many NASA centers and contractors

Drive need for a systems engineering process

…but…

- JPL institutional documentation is written with Class A-D missions in mind
- Impossible to implement full scope on ASPIRE

…therefore…

What systems process to bridge competing drivers?

Applying Existing Systems Engineering Principles

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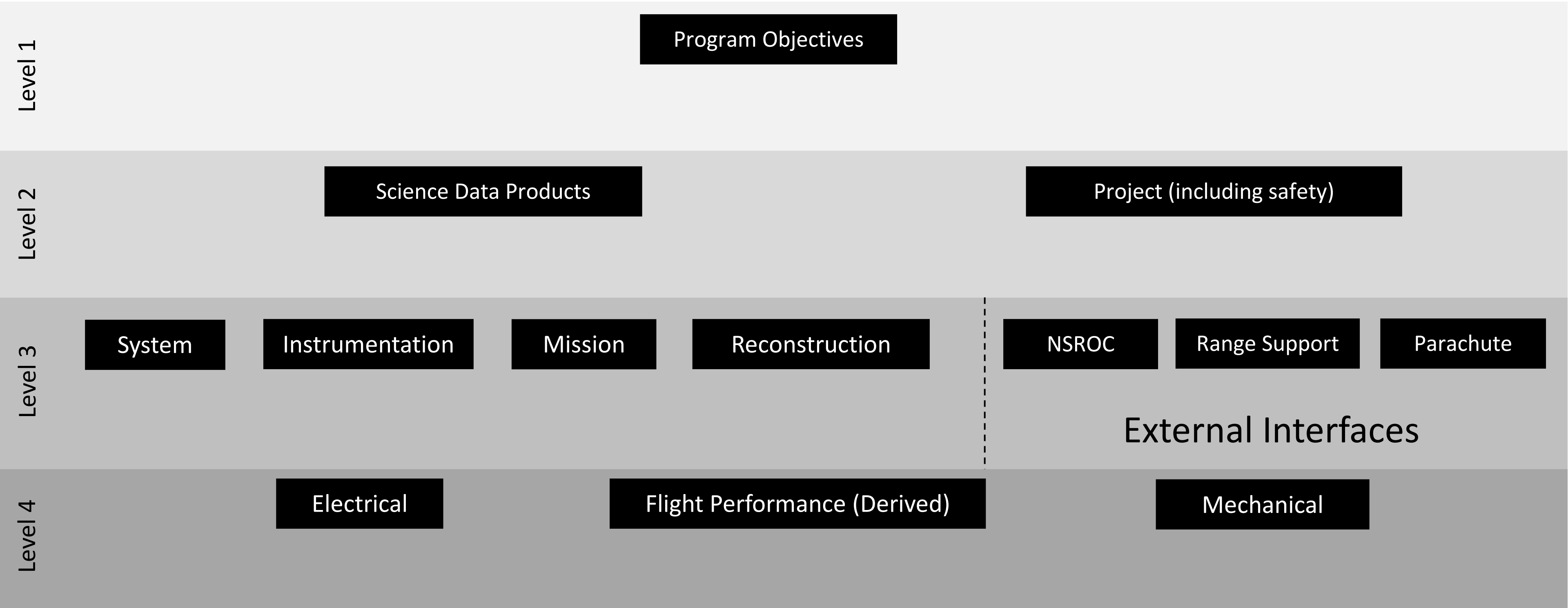
Answer: adapt existing documents by keeping all key functions and appropriately adjusting scope

Function	ASPIRE Implementation
Develop the systems architecture	Capability driven using existing sounding rocket architecture.
Develop and maintain requirements	Integrated set of requirements for Sounding Rocket Program Office (SRPO) and experiment section specific requirements. No change requests for individual requirements, instead new revisions of requirement document to include changes.
Develop and maintain interfaces	Relied on documentation of existing hardware; simple documentation of JPL/NSROC interfaces.
Manage and allocate technical resources	System architecture and design resulted in very large power and mass margins. Primarily focused on mission timeline, as-built mass properties, and data reliability instead.
Analyze and characterize the system design	Driven primarily by parallel EDL simulations
Verify and validate the system requirements and designs	Limited analysis and tests at box and subsystem level. Focused on system level test. EDL simulations independently checked and compared.
Identify, manage, and mitigate risks	Broken down into individual mission and project level risks. Tailored to account for the fact that a launch failure is not project failure.
Organize technical peer reviews	Primarily used SRPO process but more opportunity to incorporate lessons learned between flights
Manage the design	Formal engineering change requests were not created. Instead, change description, approval, and status tracked with supporting documents updated as appropriate.
Manage the systems engineering task.	Used institutional standard budgeting tools, but Baseline Change Requests conducted only at the project level and not at the element level.

- Built consensus on this approach with key stakeholders
  - Mars 2020 and ASPIRE Project Management
  - ASPIRE Principal Investigator
  - Mars 2020 Mission Assurance Manager and Quality Control Independent Authority
  - Mars 2020 EDL Phase Lead
  - Systems Engineering Organization
- Published project-internal “ASPIRE Project Guidelines Document”

Requirements

- Scope of ~150 total requirements
  - Shared ownership between JPL and WFF
  - High use of existing equipment; box-level focus on qualification of spec sheets vs. detailed box requirements
  - Analytical and simulation requirements verified to 90% confidence level
- Signed and approved as a complete document; not managed individually
- Waivers were assessed only internally to the project
- Requirement set reviewed and updated between flights
  - Ended the project on Rev. D



Verification and Validation

- Typical V&V methods were applied, but their activities were scoped appropriately for the project:
  - Inspection
    - Document: signed-off paperwork, approvals, or safety analyses
    - Hardware: agreement between ASPIRE, Mars2020, and JPL QA directorate for selective inspections on test article, and integrated vehicle workmanship
  - Analysis
    - Primarily EDL targeting analysis. Independent V&V runs by JPL and LaRC.
  - Test:
    - Unit level acceptance testing
    - Primary focus on integrated system-level testing on complete vehicle
    - Full team involvement in tests for rapid communication and issue resolution
- V&V Management – No burn-down charts; open closed status only was presented at major reviews. Items were closely tied to review products or incompressible test list.
- Issue Reporting – used Trac, an open source wiki and issue tracking software

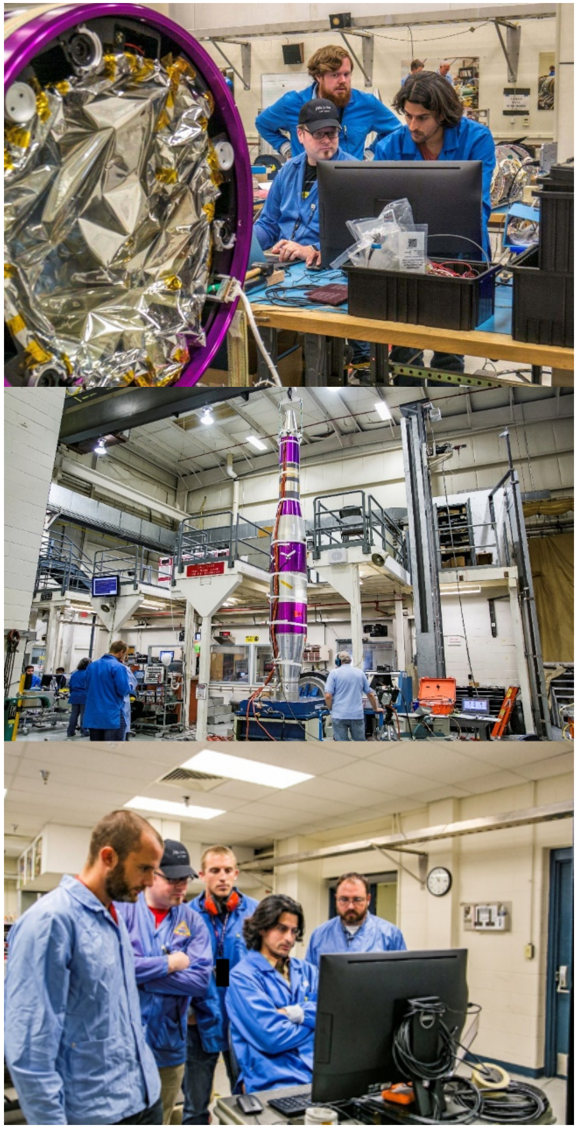


Photo credit: WFF Public Affairs Office/Berit Bland

Risk Management

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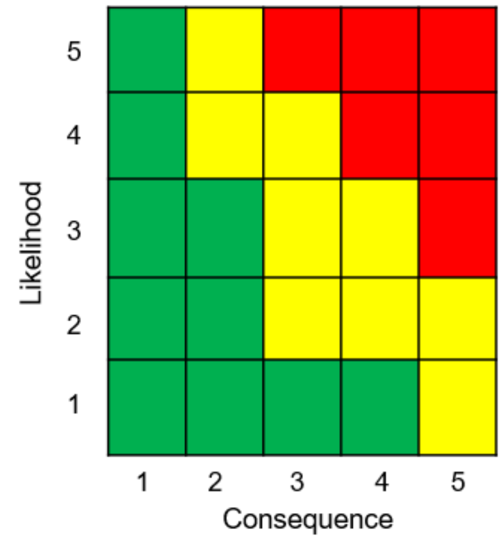
- 2 separate 5x5 matrices for each flight
  - Risk to a specific flight
  - Risk to the overall program
- Tailored likelihood and consequence definitions for the project
- Estimated likelihoods based on development
- Simple, qualitative scheme yet very effective for communicating risks to stakeholders



Risk to a Flight

L	Definition	C	Definition
1	Not Likely	1	Negligible loss of data or data fidelity
2	Low Likelihood	2	Failure of any single fully redundant instrument, or one string of a fully redundant system
3	Likely	3	Meet all minimum success criteria (MSC) with incomplete data set or failed Comprehensive Success Criteria (CSC)
4	Highly Likely	4	Failure of 1 or more MSC
5	Near Certainty	5	Failure of all MSC

Risk to the Program

L	Definition	C	Definition
1	Not Likely	1	Minor cost risk below defined threshold, or schedule slip with no change in dates (uses margin)
2	Low Likelihood	2	Launch date slip schedule impact
3	Likely	3	~1 month schedule slip
4	Highly Likely	4	Extended test program (3-6 month slip) -> leads to customer with time for only 1 redesign cycle
5	Near Certainty	5	Failure to complete sufficient launches by customer decision gate

Reviews, Changes, and Life Cycle

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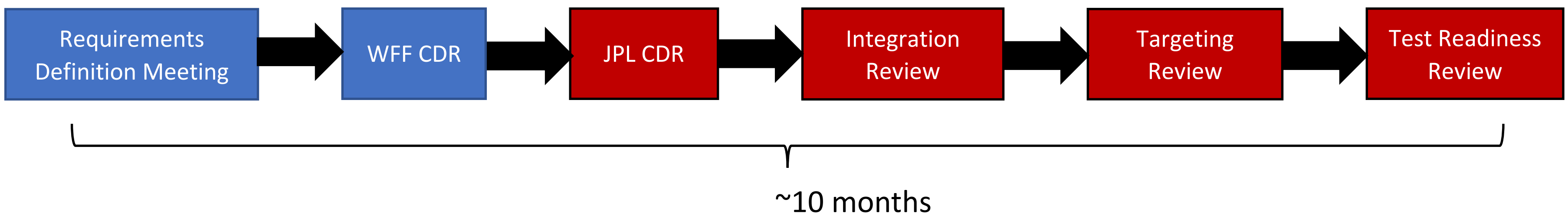
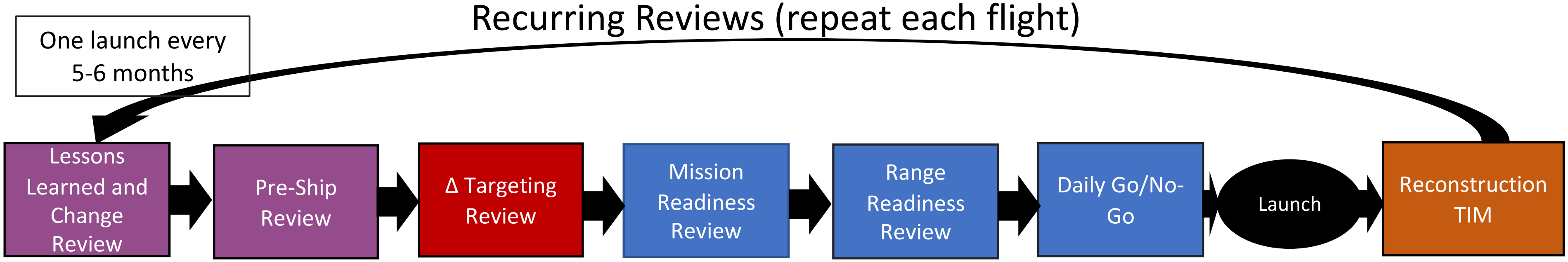
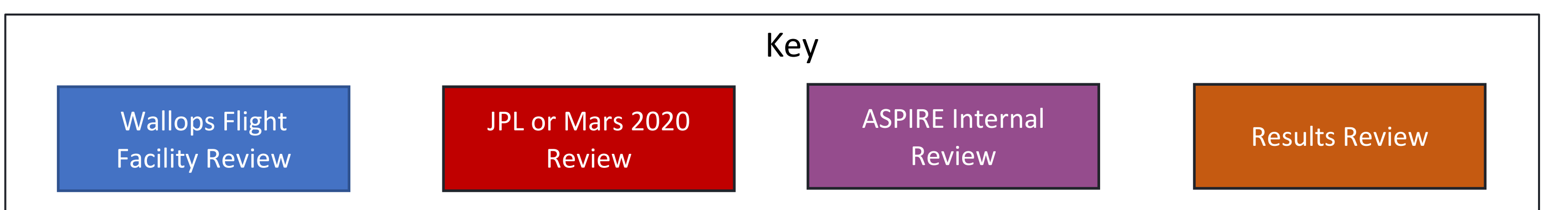
One-Time Reviews



Recurring Reviews (repeat each flight)



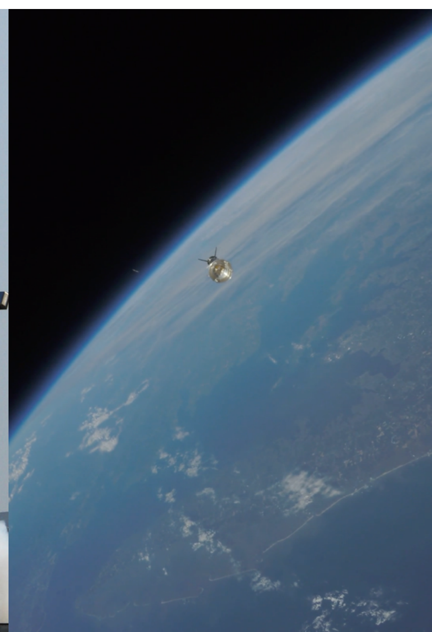
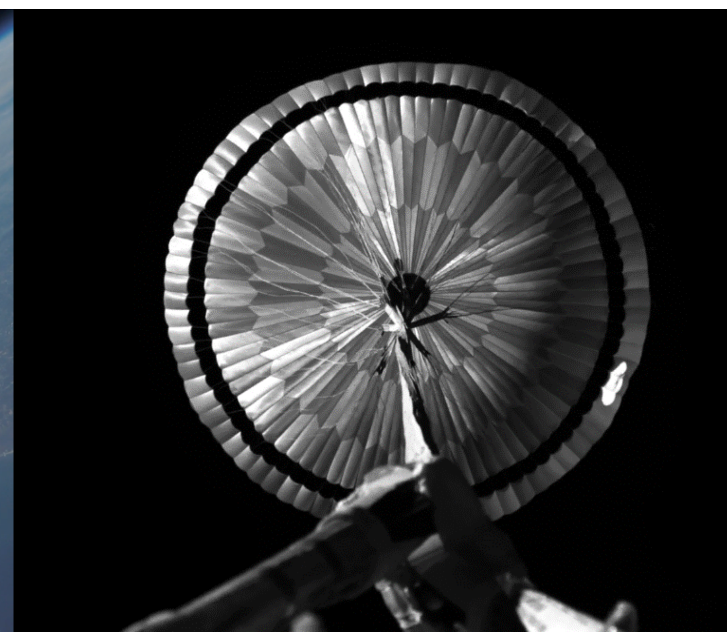
- Between flights, collected lessons learned and change requests
- Approved all changes for a given flight by this milestone to simplify assembly, integration and test
- Used sounding rocket standard review process, with additional customer and project reviews



Results

- Three successful flights!
  - All success criteria met

Flight	Date	Mach	Peak Parachute Load
SR01	Oct 4th, 2017	1.77	30.95 klbf
SR02	March 31st, 2018	1.97	55.8 klbf
SR03	September 7th, 2018	1.85	67.4 klbf


Some Lessons Learned

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Summary	Situation	Result	Take-Away
Waiver	Inside L-2 days for SR02, atmosphere predicts showed conditions just outside of requirements. Launch window was highly constrained and did not want to give up an otherwise good launch day.	A waiver was quickly reviewed and accepted, allowing launch to proceed. Actual conditions were bounded by analysis included in waiver.	A well thought out, pre-determined waiver process allowed a high degree of mission-enabling flexibility.
Unintended Change Consequence	A change request to remove a signal on load pin filter for SR03 was approved with internal change process. External reviewers at WFF provided action to assess potential aliasing or folding causing unintended data quality degradation at Mission Readiness Review.	Analysis of action showed a non-issue in this case, and was able to be completed with no schedule impact.	A robust technical process caught the issue, but later than desired, primarily leading to schedule risk. In this case, schedule savings of lean process deemed by PM to outweigh schedule risk.
Issue late in SR01 V&V	On SR01, due to initial camera testing in a non-flight-like simulator, issues in triggering high speed camera system were discovered late in integration.	Debugging the issue in an all-up configuration lead to a 1:1 schedule slip of 2 weeks. With a more representative test bed earlier, this slip could have been entirely avoided.	Low emphasis on box-level testing could lead to schedule impacts later in development. In this case, time was spent between SR01 and SR02 to develop a more flight-like testbed to avoid future issues.

Conclusions

- Rapid and effective communication with a tight-knit team was essential to managing the interfaces, reviews, and necessary changes
- A higher allowable level of risk does not mean it can be ignored, or does not have to be tracked
- It is possible to apply best systems engineering practices to a high-risk, resource-and-personnel-constrained project
- Such small, inexpensive projects can successfully answer important questions
- Captured systems engineering methods used in this paper and in JPL-internal document "ASPIRE Project Guidelines"
    - This test architecture can be used to effective test other parachute and EDL technologies in the future
    - This example can inform successful development and implementation of other lean, effective test architectures

Acknowledgements

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- Thank you to the ASPIRE team at JPL, Langley Research Center, Wallops Flight Facility, and Ames Research Center!

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Backup

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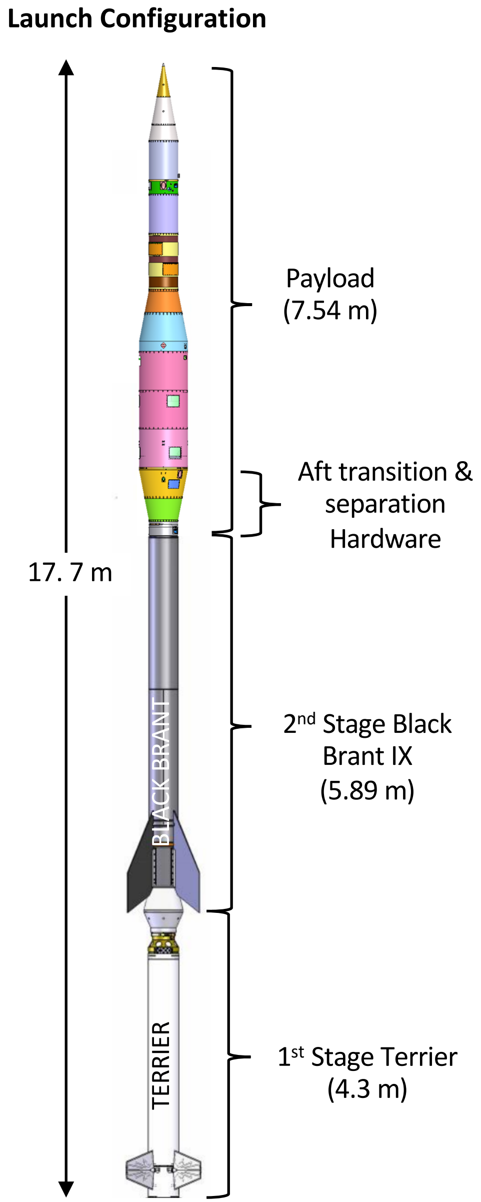
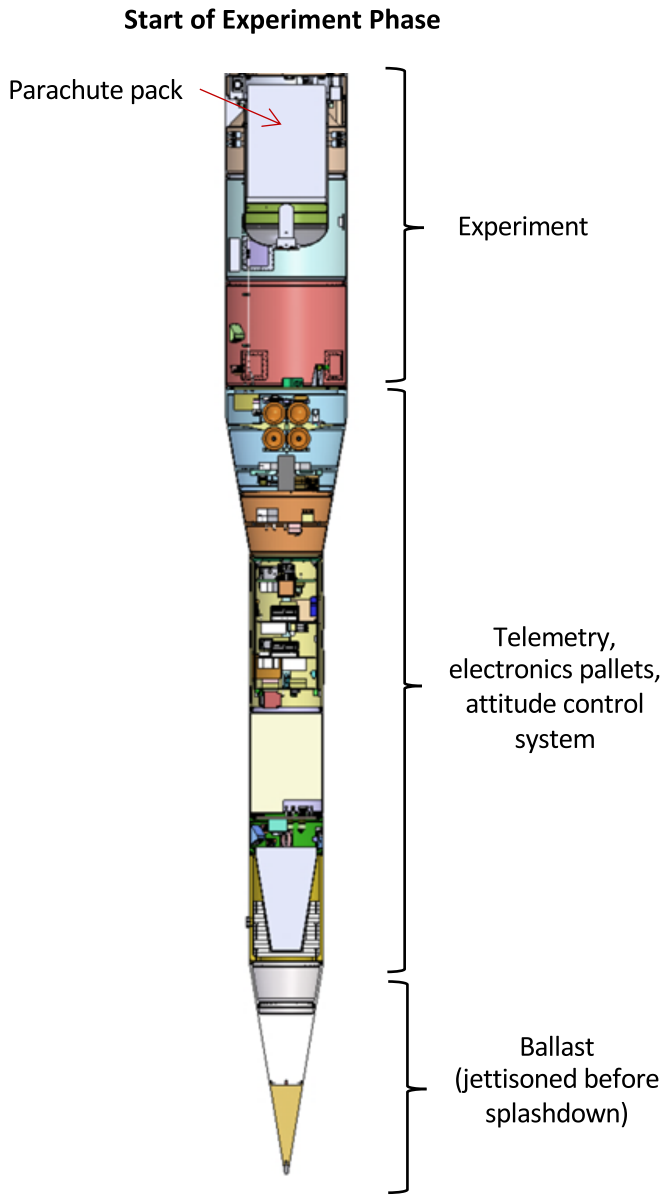
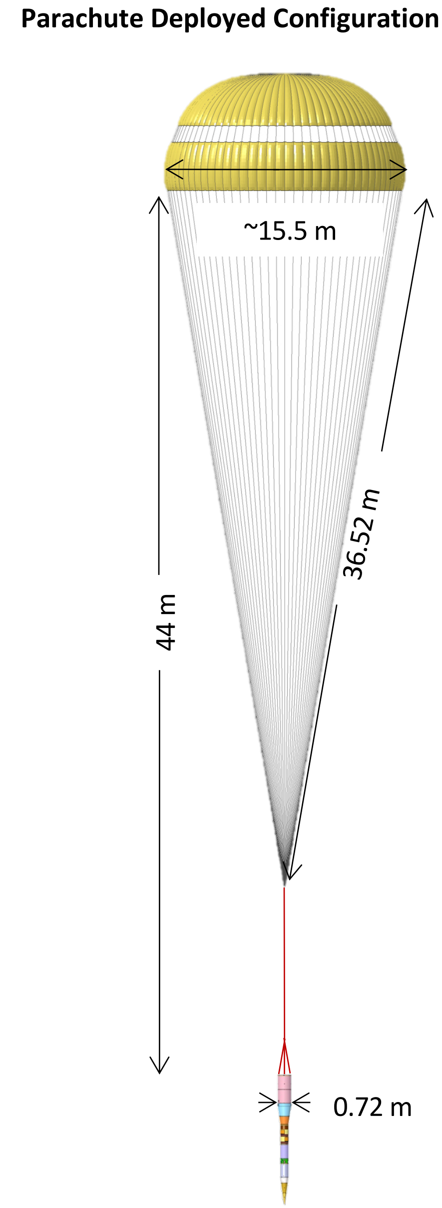
Test Architecture







Test Architecture

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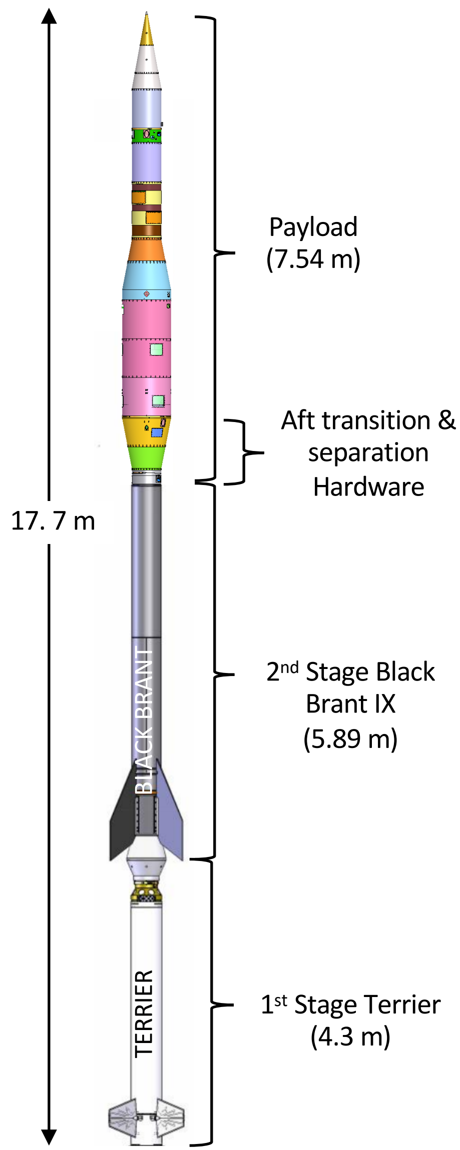

- Rail-launched Terrier Black Brant
- Spin-stabilized at 4 Hz
- Yo-yo de-spin after 2nd stage burnout
- Mortar-deployed full-scale DGB
- Cold gas ACS active from payload separation to before mortar fire
- Recovery aids:
  - Foam provides buoyancy
  - Nosecone ballast (for additional mass & aerodynamic stability) is jettisoned before splashdown
- Payload mass:
  - Launch: 1268 kg
  - Post-separation: 1157 kg
  - Splashdown: 495 kg